

THE TYCHO CATALOGUE: ASTROMETRIC AND PHOTOMETRIC RESULTS

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Abstract. The Tycho Catalogue contains basic astrometric and photometric data for a million stars on the sky, complete to about $V = 10.5$ mag. The accuracy at the catalogue epoch (J1991.25) of positions and two-colour magnitudes is generally an order of magnitude better than has hitherto been available for the majority of these stars. Results from the production and verification of the catalogue is presented. The catalogue and associated epoch photometry annex are available in machine-readable form as part of the final Hipparcos mission products.

1. The Tycho Catalogue

The Tycho Catalogue of a million stars was obtained from photon counts obtained by scanning with the Hipparcos star mapper, carried out simultaneously with the Hipparcos observations in the adjacent main field of view of the telescope.

The observational capabilities and operational principles of the Hipparcos satellite have been presented in the literature on previous occasions, with the most complete and definitive treatment contained within the published Hipparcos and Tycho Catalogues (ESA 1997). Short descriptions are given in this volume, in *Astronomy & Astrophysics* by Perryman *et al.* (1997), Høg *et al.* (1997) and van Leeuwen *et al.* (1997), and at the Venice Symposium (Perryman 1997.)

The principal observational characteristics of the Tycho Catalogue are given in Table 1. Complete details of the data, the reductions, and the properties of the final Tycho Catalogue, are published by ESA (1997), especially in Volumes 1 and 4 to which we refer in the following.

2. Astrometry

The five astrometric parameters, (α , δ), the annual parallax, π , and the proper motion components $\mu_{\alpha^*} = \mu_{\alpha} \cos \delta$ and μ_{δ} , in angular measure per unit time, are given for almost all stars in the catalogue. The catalogue includes astrometric quality flags, and indicators of variability and/or duplicity – nearly 900 000 of the catalogue entries are classified as ‘recommended’ reference stars, having good Tycho astrometric quality, and not recognised as double.

The median value of the formal (internal) astrometric standard errors given for each star (in position, parallax, and annual proper motion) are typically around 7 mas for stars brighter than $V_T \sim 9$ mag, and approximately 25 mas for $V_T \sim 10.5$ mag. The external standard errors (i.e. accuracies) are only slightly larger by a factor of 1.1 for bright stars of $V_T < 10$ mag, increasing to a factor of 1.5 larger at the median magnitude $V_T = 10.5$ of the Tycho Catalogue stars. This has been found from a comparison with the much more accurate Hipparcos values for stars common to the two catalogues. The systematic errors are less than about 1 mas(/yr).

3. Photometry

The Tycho Catalogue includes accurate and homogeneous photometric information for each star: two-colour (B_T and V_T) magnitudes derived from the Tycho (star mapper) observations; Johnson V magnitude and $B - V$ colour index, derived from the observed $B_T - V_T$ by simplified transfor-

TABLE 1. *Principal observational characteristics of the Tycho Catalogue. ICRS is the International Celestial Reference System.*

Measurement period	1989.85–1993.21
Catalogue epoch	J1991.25
Reference system	ICRS
coincidence with ICRS ¹	±0.6 mas
deviation from inertial ¹	±0.25 mas/yr
Number of entries	1 058 332
based on Tycho data	1 052 031
with only Hipparcos data	6301
Median astrometric standard errors ²	
$V_T < 9$ mag	7 mas
all stars	25 mas
Median photometric std. errors on V_T	
$V_T < 9$ mag	0.012 mag
all stars	0.06 mag
Sky density ³	~ 25 deg ⁻²
Limiting magnitude	$V \sim 11.5$
Completeness to ~ 90 per cent	$V \sim 10.5$
Completeness to ~ 99.9 per cent	$V \sim 10.0$
Total number of observations	~ 130 × 10 ⁶

¹ about all 3 axes
² ratio of astrometric external to internal errors at $V_T = 10.5$ is ~ 1.5
³ depending on galactic latitude

mations reflecting the fact that the spectral type, luminosity class, reddening, etc., are unknown for the majority of Tycho Catalogue objects; and various flags resulting from (preliminary) studies of variability based on an average of 130 transits per star during the 3 year observing period. The details of the Tycho B_T and V_T photometric system, and details of the corresponding transformations to V and $B - V$, are given in the published catalogue, and also described in the context of the Hipparcos main mission photometry by van Leeuwen et al. (1997).

Published mean photometric values were based on all transits for each star, including those transits where the star was not detected because the signal was too faint. These ‘censored’ observations were taken into account in a dedicated ‘de-censoring’ processing. In the basic Tycho data reductions only the detections with a signal-to-noise ratio larger than 1.5 in the combined photon counts from the B_T and V_T detectors provided astrometric and photometric estimates. The photometric results for individual transits, including the censored observations, are provided separately in a Tycho Epoch Photometry Annex for specific subsets of stars. These individual magnitude determinations, at the specified measurements epochs, will allow detection of variable stars and further studies of the variability of known variables.

The principal photometric characteristics are as follows. Standard errors of V_T mean magnitudes are for $V_T < 9$ and ~ 10.5 respectively about 0.012 and 0.06 mag. Errors on B_T are typically 10 per cent larger for the same values of B_T . The standard errors of individual transits in the Tycho Epoch Photometry Annex are typically 10 times larger than for the mean value of a given star.

A histogram of all stars in the Tycho Catalogue as function of V_T is given in Figure 1. The catalogue is generally complete to 99.9 and 90 per cent at respectively $V = 10.0$ and 10.5 mag. But the degree of completeness at the faint magnitudes depends also on the colour index and on the position in the sky, due to the scanning law (see Volume 4, Figures 16.4 and 16.5). The degree of completeness is approximately constant for all stars with a given value of $V_T = V_{T0} - 0.50(B_T - V_T)$ because the Tycho detection was carried out in the added photometric counts from the two channels B_T and V_T . This equation is almost equivalent to $V = V_0 - 0.70(B - V)$ where $V_0 = V_{T0}$, according to the transformation by Equations 1.3.20 in Volume 1.

The distribution of the colour index $B - V$ (Johnson system) is shown in Figure 2 of Høg *et al.* (1997) for different ranges of the galactic latitude. The bimodal structure and other features related to the HR diagramme of field stars in the solar neighbourhood are thus illustrated.

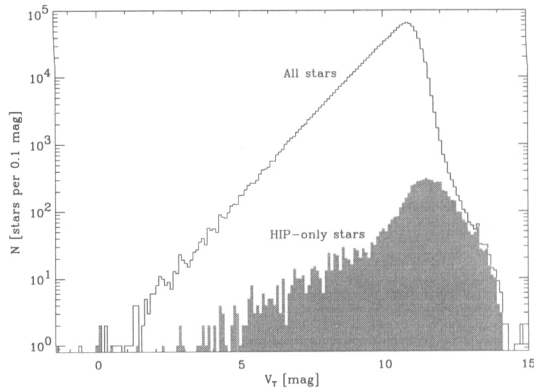


Figure 1. Histogram of all stars (upper curve) in the Tycho Catalogue as function of V_r . For the sake of completeness the catalogue also includes entries (HIP-only) for stars only observed in the Hipparcos main field and thus contained in the main Hipparcos Catalogue.

4. Applications

Many applications of the Tycho Catalogue have already been initiated. The Tycho Reference Catalogue (TRC) and the 2nd Tycho processing are described by Høg (1997b); the latter project is based on the 1000 Gbits of original Tycho photon counts. Furthermore, the *Celestia 2000* is a CD-ROM for catalogue interrogation (see Volume 1), the *Millenium Star Atlas* contained in the Volumes 14–16 will show all Tycho stars. The Tycho Catalogue will be or has been used as an astrometric reference frame for, e.g., space craft control by ESA/ESOC, control of the AXAF satellite, CCD drift scan, CCD astrophotography, calibration of the USNO A 1.0 etc., calibration of the GSC 1.1, calibration of the GSC II, calibration of quasar fields, calibration of a multi-fibre spectrograph.

The photometric reference stars of the Tycho Catalogue will be used for calibration of the GSC 1.1, calibration of the USNO A 1.0 etc., calibration of variable star observations by amateurs. Finally, e.g., new nearby stars have been found, kinematic studies will be based on the Tycho Reference Catalogue, and new variable stars will be found from the Tycho epoch photometry.

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